

# A CLOSED RACEWAY FOR THE CULTURE OF SHRIMP<sup>1</sup>

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## ABSTRACT

Methods for intensive culture of penaeid shrimp in closed raceway systems are being tested at the National Marine Fisheries Service Galveston Laboratory. Encouraging results have been obtained with white shrimp (Penaeus setiferus) and brown shrimp (Penaeus aztecus) reared at high densities through the postlarval and juvenile stages. Interesting features of this raceway are: 1) no substrate is used; 2) the raceway has no "ends" where animals might concentrate; and 3) water circulation, aeration and partial removal of wastes are all accomplished with simple air-lift pumps.

## INTRODUCTION

Because the life cycle of penaeid shrimp is known (Pearson, 1939), it is reasonable to assume that, if we could duplicate natural conditions, we could expect good growth and survival. Unfortunately, in a large static pond or flow-through system, this is very costly or impossible. In this study a different approach, involving a closed system, was taken to provide optimum environmental conditions.

To culture many shrimp within a confined area, we constructed a system that provides control of water quality, temperature, water movement, and waste removal. The cost of building and

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operating the system was a major consideration in its design.

Since water quality is the single most important environmental factor in the culture of aquatic plants and animals, the availability and cost of clean water are of primary importance. In a closed system, water quality is maintained in part by removal of waste products. The addition of dissolved oxygen to the water is another means of maintaining water quality. Spotte (1970) suggested that one of the most serious problems facing the culturist today is a chronic ammonium level. If the dissolved oxygen content can be maintained close to saturation, the susceptibility of the animals to ammonia poisoning is greatly reduced. It has been shown that even small amounts of un-ionized ammonia can be harmful; exposure to sublethal levels of ammonia can affect growth rates, physical stamina, and disease resistance (Burrows, 1964). Assuming that salinity has an effect upon growth and survival of shrimp (Zein-Eldin, 1963 and Zein-Eldin and Aldrich, 1965) the ability to adjust salinity to optimum levels in a closed system is an asset. Other products of the decomposition of wastes such as nitrates, phosphates, carbon dioxide, and dissolved organic matter must be removed from the water in a closed system or water quality will deteriorate.

Temperature is a factor controlling metabolism and therefore can be directly correlated to growth rates of shrimp (Zein-Eldin and Griffith, 1966). For most efficient use of facilities in terms of production, temperatures should be maintained near optimum levels year round.

Circulation of the water is another critical parameter, for without it problems with water quality frequently occur. Proper circulation facilitates distribution of food and oxygen, and the removal of wastes; however, water flow must be designed with the behavior and tolerances of the shrimp in mind.

Removal of two general types of wastes from the system must be accomplished. The first is particulate matter such as feces, waste food, and debris, and the second is dissolved inorganic and organic compounds which accumulate in the water. While a variety of techniques exist for removing these wastes, the methods used in the raceway described herein were physical filtration, aeration or air stripping, and the growth of algae in the system.

#### DESCRIPTION OF RACEWAY

Two raceways (I and II) were built in existing rectangular concrete tanks in an abandoned basement. The flat floor of the basement served as the bottom for the tanks. Before the raceway panels were fabricated, the concrete tanks were coated with a thin layer of cold-process roofing tar. Measurements of the tanks were 5.9 x 2.7 x 1.0 m; bottom surface area was 16 m<sup>2</sup>; and water volume was 12,000 liters when filled to a depth of 75 cm.

The raceway (Figure 1) was designed so that the water mass was divided into narrow channels through which the water flowed in a predetermined pattern. We chose as wall panels for the channels a non-toxic material that could be shaped. Panels were built of clear flat fiberglass 1.9 mm thick. To hold the fiberglass in the desired positions, wooden slats (76 cm long, 40 mm wide, 6 mm thick) were bolted together with the fiberglass sandwiched between them. These slats were suspended from a wooden frame which lay across the top of each tank. All nuts and bolts were either PVC (polyvinyl chloride) or nylon. Raceway panels were held in place 5 cm above the bottom of each tank. The 5-cm clearance aids in draining and harvesting as well as giving the shrimp freedom to move about on the bottom.

Air-lift pumps were constructed of 38-mm schedule 40, service weight, plastic pipe. The top of each pipe was fitted with a 90° socket elbow, which had been pre-drilled to accommodate a 6-mm air line. The air line extended down the inside of the pipe to about 50 mm from the bottom of the pipe. A small lead weight and an air stone were attached to the end of the air line. The bottom of each air-lift pipe was cut on a 45° angle. The pipe was oriented so that the water flowed into the lower end of the pipe. The total pipe length (with the elbow attached) was the same as the water depth in the raceway. The air-lift pipes were attached to the panels with plastic pipe clips, which were bolted to the panels. The bottom of the tank was flat with no obstructions. The placement of each air-lift pump is shown in Figure 1.

Since space was available in the corners of the raceway, we built a small mechanical filter, operated by an air-lift pump, and placed it in one corner. The filter (Figure 1) consisted of a 9.5-liter plastic bucket, with a perforated plastic bottle bolted to its bottom. The top of the plastic bottle was cut to accommodate a 38-mm plastic pipe, a duplicate of the air-lift pipes used in the raceway. With the air-lift pipe in place, the bucket was filled with crushed oyster shell (pellet feed size) and submerged.

Initially the raceways were outdoors and exposed to the elements. With the approach of winter, however, we enclosed them under a frame structure with a fiberglass roof and polyethylene sides so that filtered natural sunlight was present. A natural gas heater was suspended in the enclosure to help maintain desired temperatures.

#### OPERATION

##### Circulation

The general principles of air-lift pumps have been understood for many years. Carl E. Loëscher, a German mining engineer invented it in 1797. Additional information about air-lift pumps was presented by Ward and Kessler (1924) and Spotte (1970).

The air-lift pumps in our system perform a number of beneficial functions including the following:

- 1) Raising water from the bottom of the tanks to the surface.
- 2) Creating a controlled flow of water through the raceway which aids in both the distribution of food and the removal of wastes.
- 3) Aerating the water thus adding dissolved oxygen, and removing some harmful waste products by air stripping.
- 4) Reducing water temperature 1 to 2 C during hot weather.

The placement of each air-lift pipe was determined primarily from the erosion mechanics of stream building (Hjulström, 1939). For example, a young stream erodes the bottom along the entire stream bed's length, and cuts into the bank on curves with deposition occurring along the inside bank. To eliminate this zone of deposition in the raceway, it was necessary to install air-lift pumps on the inside of the curves.

To maintain circulation in the end zones of the tanks, we installed either air stones or air-lift pumps (Figure 1). Panels were placed so they did not touch one another or the walls of the tank thus eliminating cracks where food might accumulate and foul.

Air was supplied by a compressor, with the line pressure maintained at 1.3 kg per cm<sup>2</sup>. Air flow through each air-lift pump was maintained at 2.8 liters per minute. Discharge volumes ranged from 57 to 95 liters of water per minute with an average of 76 liters per minute per air-lift pump. It was observed that shrimp were often sucked through the air-lift pumps, with no apparent damage.

Flow rates through the bucket filters averaged 38 liters of water per minute. Only one filter was used per raceway through August 4, but thereafter an additional filter was added to each raceway. Bucket filters were removed and washed each morning.

If the discharge from the air-lift pumps is constant, then the speed at which the water is moved can be controlled by the position of the discharge fitting (90° elbow). Current speed was maintained at 0.6 cm per second, utilizing 2.8 liter of air per minute in each of 47 pumps.

Unfortunately, the walls and floor of the tanks were not watertight, therefore, we lost water due to seepage. To replace water lost by seepage and evaporation, it was necessary to add 95 liters every other day.

### Water Quality

Due to the thorough mixing of the water in the raceway, no stratification or stagnation occurred. Numerous measurements of water quality were made daily; however, only measurements made between 8:00 a.m. and 9:00 a.m. are shown on Figure 2. Temperature measurements taken in the two raceways were almost identical, differing no more than 0.2 C. Therefore, in Figure 2 temperature values for the two raceways are plotted on one line.

It became apparent that it was not necessary to monitor the level of dissolved oxygen in the water. The lowest level measured in either raceway was 80% of saturation. This measurement was taken in the morning just before sun-up.

Salinities in the two raceways were usually similar, except that from August 15-27 when we were adding fresh water to raceway II, a difference of 3 ppt was observed (Figure 2). From September 6, to the termination of the study, salinity values were the same in both raceways. A drop in salinity occurred during September 24-26 when we had a heavy rain. The hydrogen-ion concentration (pH) was fairly stable throughout the experiment ranging from 7.9 to 8.3 (Figure 2).

### Feeding

The food used during most of this study was a commercial feed for tropical marine fish, "Tetra Marin"<sup>2</sup> (staple food). The food contained 45% crude protein, 6% crude fat, and 6% crude fiber. The food contains: fish meal, crab meal, brine shrimp, mussel meal, lobster meal, halibut meal, beef heart meal, halibut liver, marine copepods, kelp, oat flour, wheat germ oil, agar-agar, seaweed, and bone charcoal; however, the proportions of the various ingredients are not given by the manufacturer. Although the flakes were not of uniform size, examination revealed that they were about 0.1 mm thick with the largest flakes being 10 mm in diameter. The flake floats for several minutes (5 to 7) before sinking and does not foul the water as readily as some feeds tested.

The food was sprinkled in front of one of the air-lift pumps until the entire water surface was covered. Due to the unique circulation within the system, the food spreads uniformly. When the food sank, the circulation and action of the air-lift pumps kept the flake in suspension and fairly well distributed throughout the system. Since food particles have no place to accumulate, fouling has been eliminated. Shrimp swam to the surface and began feeding even before the flake sank. They were observed swimming upside down, just below the surface, gathering

<sup>2</sup>The use of trade names in this publication does not imply endorsement of commercial products.

many flakes before righting themselves. A larger flake of "Tetra Marin" (roughly 25 mm in diameter) was tested, which appeared to be more suitable than the smaller flake for juvenile shrimp.

Although the study was performed utilizing primarily "Tetra Marin," we did perform one experiment with an extruded feed FDSC 5-5/70B (Meyers and Zein-Eldin, 1972).

Since survival in our closed system was of considerable importance, we felt it was imperative that we count the entire population at intervals. We were able to transfer all the water from either raceway, store it in a reservoir, count the shrimp, replace the original water and the shrimp and continue the experiment. While a raceway was empty, we examined the system and made necessary adjustments. In no instances did we observe indications of anaerobic decomposition or hydrogen sulfide production.

#### Harvesting

Harvesting was accomplished by pumping water out of the raceway with a submersible pump until only 5 cm of water remained. The raceway floor drain was then opened and the remaining water and shrimp drained into a sump. Shrimp were then removed from the sump with nets.

#### EXPERIMENTAL RESULTS

The primary objective of the raceway experiments was to determine optimum stocking densities by monitoring survival and growth. If good survival could be maintained, then the secondary objective, growth, would be considered. Once growth slowed or stopped the feeding level was increased to see if renewed growth would occur. If the increase in ration had no apparent effect, then the population was thinned.

On July 17, 1972, 11-day-old white shrimp (*Penaeus setiferus*) raised at the National Marine Fisheries Service Galveston hatchery, were transferred to raceways I and II at a length of 6 mm and a weight of 0.0001 g. Initial stocking densities were 200,000 (12,500 per m<sup>2</sup>) and 38,000 (2,370 per m<sup>2</sup>), respectively. The 38,000 stocked in raceway II was a number similar to what might be stocked in a 0.4 ha pond. The 200,000 placed in raceway I were merely the remainder of the population on hand. Growth and survival during a series of experiments in these raceways are presented in Figure 3.

#### Raceway I, Experiment I

The day the shrimp were stocked, feeding once a day began at 94% of the initial body weight. This rate (21.2 g of "Tetra

Marin" per day) continued for 16 days, at which time the frequency was increased to two feedings per day of 63.6 g each. However, it was apparent that we were still underfeeding the population. Unfortunately, sufficient food was not available to increase our feeding level to one comparable to raceway II; therefore, we decided to harvest. On August 8, when the population was harvested, 90% had survived after a period of 22 days. The shrimp harvested averaged 12.1 mm in length and .009 g in weight.

#### Raceway II, Experiment I

A single initial feeding of 21 g was made on the first day of this experiment. One week passed before additional food was provided. Then feed was provided at a rate of 6.4 g per day for the next 10 days. August 4, the feeding level was increased to 92 g per day. Although the shrimp in raceway II increased an average of 0.6 mm in length and 0.002 g in weight per day, we decided to harvest and transfer a portion of them to raceway I. Aliquot counts of this population revealed that 94% of the shrimp had survived for a period of 28 days.

Growth varied appreciably between the two experiments. Shrimp in raceway II were almost twice as long and eight times heavier when harvested than those in raceway I. This difference can be directly attributed to the feeding level. Raceway II contained 38,000 shrimp as compared to 200,000 shrimp in raceway I, but the total food supplied to each raceway was about the same. In raceway I, 1.1 kg of food were fed producing 1.6 kg of shrimp, whereas in raceway II, 1.1 kg of feed produced 2.6 kg of shrimp.

#### Raceway I, Experiment 2

The second experiment began August 14 with shrimp from raceway II, which averaged 22.4 mm and 0.073 g. Stocking density was 625 per m<sup>2</sup> in raceway I.

Initial observations on the population revealed that growth had slowed appreciably. The initial feeding level of 130 g per day was increased to 273 g per day after 8 days. Within a few days good growth resumed. After 49 days we decided to harvest to determine survival. Of the 10,000 stocked, 97% was harvested. Average daily growth for the 49-day period was 0.62 mm in length and 0.02 g in weight. The mean size was 52.6 mm and 1.05 g. During this phase of the study, 12.0 kg of food were fed and 9.4 kg of shrimp were produced.

#### Raceway II, Experiment 2

Shrimp from the previous experiment in this raceway were restocked on August 14 at a length of 22.4 mm. Stocking density

was 1,614 m<sup>2</sup>. Feed was provided at a rate of 170 g per day. The experiment was terminated after 18 days. At this time shrimp averaged 31.0 mm and 0.22 g. Not only was growth poor, but cannibalism was observed, indicating an inadequate food supply. Only 89% of the shrimp survived. We fed 3.1 kg of food to produce 3.2 kg of shrimp in this experiment.

#### Raceway I, Experiment 3

On October 2, raceway I was restocked with 2,500 shrimp (156 per m<sup>2</sup>) from the previous experiment in that raceway. Stocking size was 52.6 mm and 1.05 g, and initial feeding rate was 373 g a day. Although the average gain in weight per day was more than in the preceding experiment, the growth in length was slower. On October 18, after a period of 16 days, the feeding level was increased to 510 g a day. Routine measurements of the population 9 days later revealed that good growth had resumed.

Of particular interest was the daily gain in weight which had more than doubled. On November 3, or after 32 days, we decided to increase the feeding level to 849 g a day. After a total of 63 days, this experiment was terminated. Ninety-seven percent of the shrimp, averaging 86.6 mm and 4.56 g, were harvested. Overall average growth for this experiment was 0.54 mm and 0.06 g per day. A total of 40.6 kg of food was fed to produce 8.5 kg of shrimp.

#### Raceway II, Experiment 3

Since an experiment at a stocking level of 625 per m<sup>2</sup> was in progress in raceway I, we decided to restock raceway II at a density of 312 per m<sup>2</sup>. Mean stocking size was 31.0 mm and 0.48 g. Growth was good for about 12 days, averaging 0.88 mm and 0.29 g, but then it began to slow down. On October 2 the feeding level was increased from 168 to 255 g a day. After 3 days, good growth (0.9 mm and 0.07 g per day) was reestablished. Since the shrimp had now been held for 35 days, we decided to harvest to determine survival. Of the original 5,000 shrimp stocked, 4,950 were still alive. Because of a pump failure, this tank was inadvertently refilled half with the original water and half with fresh seawater. This is the only instance in this series of experiments when any significant water change took place.

The remaining 4,950 shrimp were placed back in the tank where growth during the first 13 days was poor, averaging 0.2 mm and 0.01 g per day. On October 18, feeding was increased from 255 g a day to 509 g a day, and on November 3, 64 days after the experiment began, the shrimp in raceway II were harvested. Ninety-five percent of the population had survived, and shrimp averaged 66.8 mm in length and 2.25 g in weight. During this experiment 17.5 kg of food had been fed producing 9.6 kg of shrimp.

#### Raceway II, Experiment 4

During the spring of 1972 we tried several diets in a closed raceway which had an under-gravel filter. Each diet, including "Tetra Marin" had fouled wherever it accumulated on the filter. Since we now had some experience with our new raceway, and had been able to use successfully a diet which had fouled before, we decided to retest one of the original diets.

Raceway II was set up November 3 with 1,000 shrimp removed from raceway II. These shrimp averaged 66.8 mm in length, 2.25 g in weight, and were stocked at a density of 63 per m<sup>2</sup>. The feed tested was an extruded diet described by Meyers and Zein-Eldin (1972). This food was partially crushed so that the pieces were roughly 5 to 10 mm long.

Since this was a new diet which immediately sank to the bottom, we began feeding at levels of 112, 140, and 160 g per day for the first 3 days. The food was spread manually throughout the raceway and could be seen on the bottom. It was not until the third day that the shrimp began to feed, and on the fourth day the feeding level was increased to 219 g a day. Even at this feeding level, samples of the population revealed poor growth, averaging 0.08 mm and 0.01 g per day after a 2-week period. Feeding was increased to 360 g a day and maintained at that level until the termination of the study.

It was not until November 24, after a period of 24 days, that good growth (0.09 g per day) was first observed. On December 1, 28 days later, we harvested the population, after noting some cannibalism. Ninety-seven percent of the population (averaging 80.8 mm and 3.82 g) survived to harvest. A total of 8.8 kg of food had been fed, producing 1.4 kg of shrimp.

#### SUMMARY

In preliminary experiments the closed raceway system described was demonstrated to be an effective approach to rearing penaeid shrimp under crowded conditions. Sufficient water quality was maintained to rear shrimp up to a density of 690 g/m<sup>2</sup>. New uses of the air-lift pump and the continuous plant growth in the system were instrumental in maintaining this high biomass.

Costs of operation have not been developed since the system is an experimental one and frequent changes are being made. It is clear that the system provides a relatively inexpensive means of rearing small postlarval shrimp to a size (20-30 mm) more suitable for stocking ponds.

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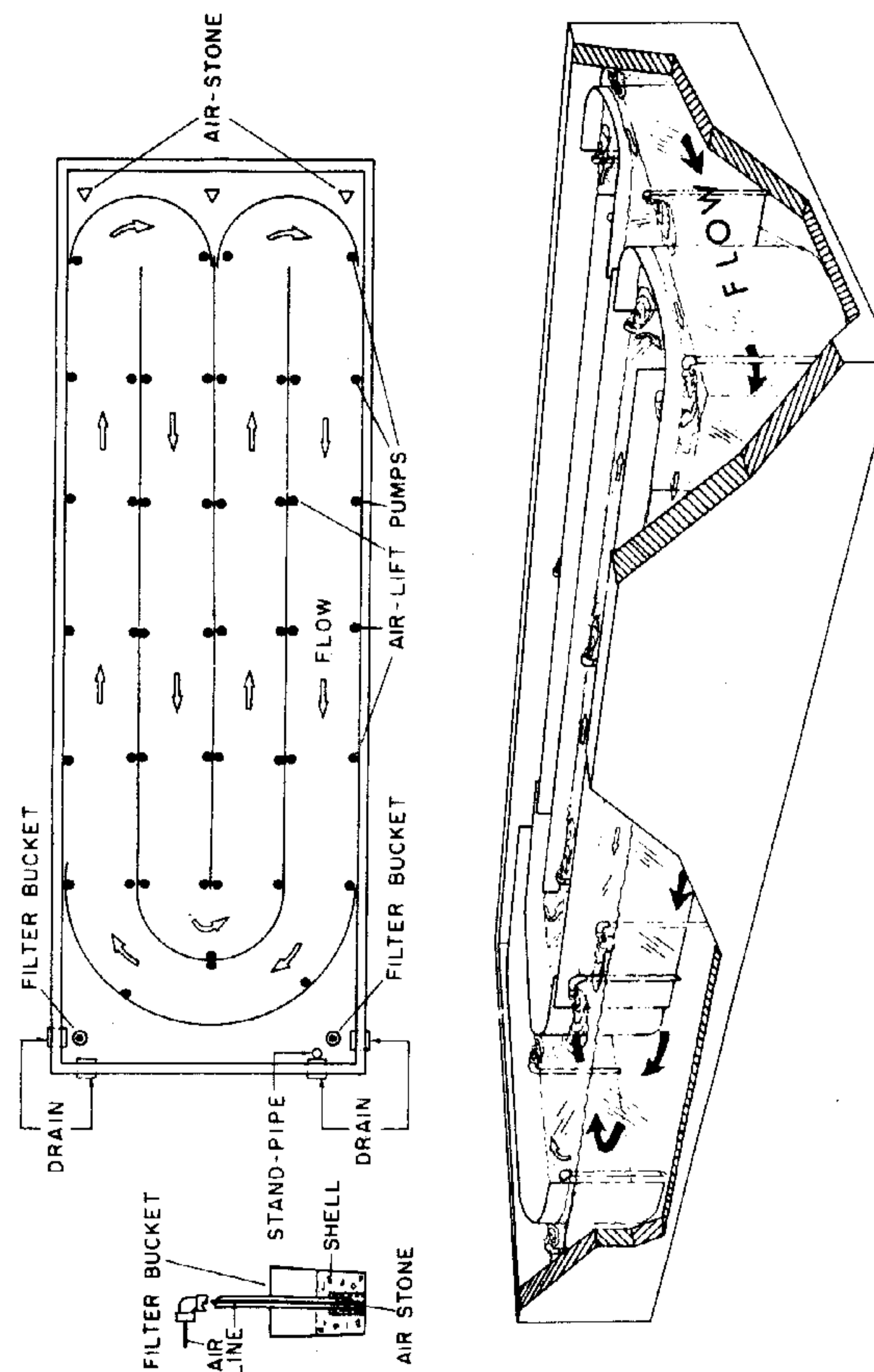


Figure 1. Top view and cut-away drawing of raceway system.

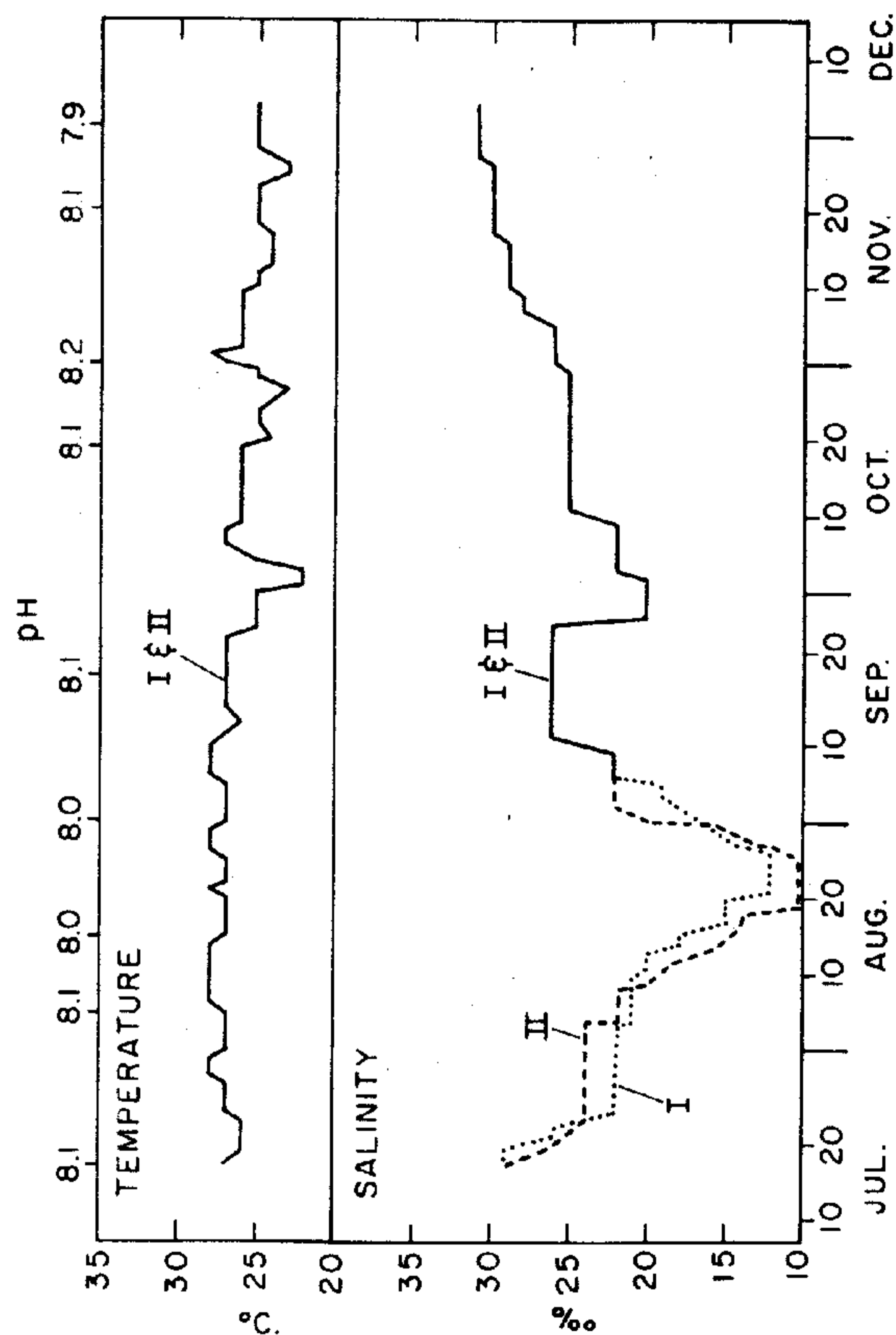


Figure 2. Measurements of pH, temperature and salinity in raceways I and II during this study.

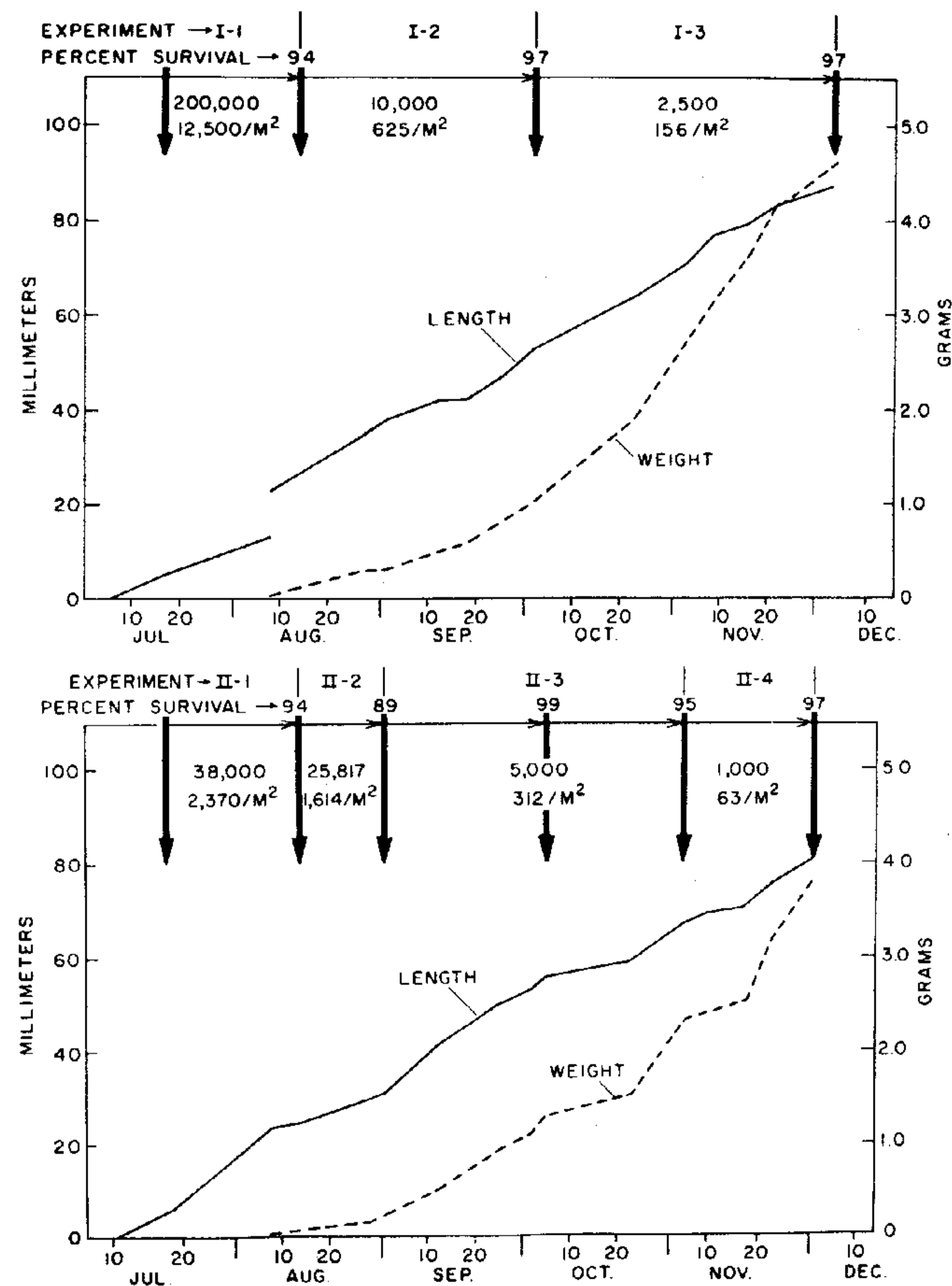


Figure 3. Growth and survival of white shrimp during a series of experiments in raceway I (above) and raceway II (below).